DTU Library

Multispecies fisheries management in the Mediterranean Sea: application of the Fcube methodology

Maravelias, C.D.; Damalas, D.; Ulrich, Clara; Katsanevakis, S.; Hoff, A.

Published in:
Fisheries Management and Ecology

Link to article, DOI:
10.1111/j.1365-2400.2011.00801.x

Publication date:
2012

Fisheries Management and Ecology [Volume 19, Issue 3,](#) pages 189–199, June 2012
http://dx.doi.org/10.1111/j.1365-2400.2011.00801.x

SIXTH FRAMEWORK PROGRAMME

Scientific Support to Policies

http://ec.europa.eu/research/fp6/ssp/aframe_en.htm

Multispecies fisheries management in the Mediterranean Sea: application of the Fcube methodology

Christos D. Maravelias[1], Dimitrios Damalas[1], Clara Ulrich[2], Stelios Katsanevakis[1] & Ayoe Hoff[3]

[1] Hellenic Centre for Marine Research, 46.7 km Athens-Sounio, 19013 Anavyssos, Attica, Greece. tel: +30 210 9856703; fax: +30 210 9811713; e-mail: cmaravel@ath.hcmr.gr
[2] DTU Aqua, Charlottenlund Castle, 2920 Charlottenlund, Denmark. Email: clu@aqua.dtu.dk
[3] University of Copenhagen, Institute of Food and Resource Economics, Rolighedsvej 25, 1958 Frederiksberg C, Denmark. Email: ah@foi.dk

ABSTRACT
The ecosystem approach (EA) advocates that advice should be given based on a holistic management of the entire marine ecosystem and all involved fisheries and fleets. Recent developments have advanced to multi-species, multi-fisheries advice, rather than on a single species/fleet/area stock basis, bridging the gap between existing single species approaches and the needs of the EA. The 'Fcube' method estimates potential levels of effort by fleet in mixed fisheries situations to achieve specific targets of fishing mortality. Data on effort, landings and socioeconomic parameters were used for coastal and trawl fisheries in the Aegean Sea. Results pointed out the strengths and weaknesses of alternative management strategies from both a biological and socioeconomic perspective. Fcube revealed the importance of effort control in the coastal fisheries that are still managed with no effort restrictions. The present findings, although preliminary, revealed that stringent cuts to effort and catch levels are required if the EA management goals are to be met. The Fcube methodology, initially developed for mixed fisheries advice in northern European waters that are managed with TACs, it also proved promising in providing advice to no-TAC fisheries.

Keywords: fleet, effort, socioeconomics, ecosystem approach, advice, demersal, TAC, landings

*Corresponding author: tel: +30 210 9856703; e-mail: cmaravel@ath.hcmr.gr

Article first published online: 21 Oct 2011

Multispecies fisheries management in the Mediterranean Sea: application of the Fcube methodology.

Christos D. Maravelias, Dimitrios Damalas, Clara Ulrich, Stelios Katsanevakis & Ayoe Hoff.

Christos D. Maravelias, Hellenic Centre for Marine Research, 46.7 km Athens-Sounio, 19013 Anavyssos, Attica, Greece. tel: +30 210 9856703; fax: +30 210 9811713; e-mail: cmaravel@ath.hcmr.gr

Dimitrios Damalas, Hellenic Centre for Marine Research, 46.7 km Athens-Sounio, 19013 Anavyssos, Attica, Greece. Email: shark@ath.hcmr.gr

Clara Ulrich, DTU Aqua, Charlottenlund Castle, 2920 Charlottenlund, Denmark. Email: clu@aqua.dtu.dk

Stelios Katsanevakis: Hellenic Centre for Marine Research, 46.7 km Athens-Sounio, 19013 Anavyssos, Attica, Greece. Email: skatsan@ath.hcmr.gr

Ayoe Hoff, University of Copenhagen, Institute of Food and Resource Economics, Rolighedsvej 25, 1958 Frederiksberg C, Denmark. Email: ah@foi.dk

Author for correspondence:

Christos D. Maravelias, Hellenic Centre for Marine Research, 46.7 km Athens-Sounio, 19013 Anavyssos, Attica, Greece. tel: +30 210 9856703; fax: +30 210 9811713; e-mail: cmaravel@ath.hcmr.gr

Acknowledgements

This work was prepared with financial support provided by the Commission of the European Communities Directorate General for Fisheries (DG XIV) 6th Framework RTD program ‘Specific Support to Policies’, under contract no 044168 “AFRAME, A framework for fleet and area based fisheries management”.

Abstract

The ecosystem approach (EA) advocates that advice should be given based on a holistic management of the entire marine ecosystem and all involved fisheries and fleets. Recent developments have advanced to multi-species, multi-fisheries advice, rather than on a single species/fleet/area stock basis, bridging the gap between existing single species approaches and the needs of the EA. The ‘Fcube’ method estimates potential levels of effort by fleet in mixed fisheries situations to achieve specific targets of fishing mortality. Data on effort, landings and socioeconomic parameters were used for coastal and trawl fisheries in the Aegean Sea. Results pointed out the strengths and weaknesses of alternative management strategies from both a biological and socioeconomic perspective. Fcube revealed the importance of effort control in the coastal fisheries that are still managed with no effort restrictions. The present findings, although preliminary, revealed that stringent cuts to effort and catch levels are required if the EA management goals are to be met. The Fcube methodology, initially developed for mixed fisheries advice in northern European waters that are managed with TACs, it also proved promising in providing advice to no-TAC fisheries.

Keywords: fleet, effort, socioeconomics, ecosystem approach, advice, demersal, TAC, landings

Introduction

In its simplest form a fishery consists of one fleet exploiting a single stock of a single species in a single area. After exhausting the quota of a given stock, it is common practice for fishermen to continue fishing to utilize the quota of other species. This leads to high grading, discards and/or illegal landings of their over-quota catches (ICES 2008). The ecosystem approach to fisheries management in line with the United Nations' Sustainability Summit (UN 2002) and the European Marine Strategy Framework Directive (EC 56/2008) aims to avoid such risk by shifting focus from single stocks towards much broader range of impacts caused by fishing activities. Therefore, scientific management advice for mixed fisheries is requested on a fleet's or fishery's basis rather than for single stocks in order to reduce the risk of failing predefined goals.

FAO (2010) reports at least forty four management/advisory bodies worldwide that try to deal with fleet specific advice for some time and face the difficulties arising when socioeconomic and biological requirements have to be met simultaneously. Various methodologies have been developed and analyzed in recent years. Promising tools brought into action are MTAC (Vinther *et al.* 2004) and the “elasticity” (Da-Rocha Álvarez & Gutiérrez-Huerta 2005) methods. The aforementioned methods have been very sensitive to the period of the time series used in the inputs, and early in 2006 a new approach the “Fleet and Fisheries Forecast method” (F^3 or Fcube) has been presented at the 2006 WKMIXMAN (ICES 2006) and tested in the 2006 ICES assessment working groups. This new Fcube framework (Ulrich *et al*. 2008; 2011; ICES 2006; 2007; 2008; 2009) focuses on fisheries and fleets rather than stocks, thus providing a bridge between the traditional single-species advice and the ecosystem approach to fishery management.

The Mediterranean demersal fisheries have an essentially multispecies nature with up to 100 species in some fisheries (Caddy 2009). There is a high interaction between gears and fleet segments, since most of the main target species are exploited by more than one fishing technique or strategy, each often concentrating on individuals of different sizes (Caddy 2009). There are certain common management measures in EU countries deriving from the application of the Common Fisheries Policy. The Mediterranean fisheries are generally managed through effort control rules and technical measures, such as closed seasons, closed areas, limited issue of new licenses, minimum landing size (MLS), mesh size regulations, and maximum size of fishing gears (TAC only apply to bluefin tuna). However, such restrictions differ between countries or even among regions and/or fisheries of the same country. For example, the Greek Aegean Sea coastal fisheries are regulated exclusively through technical measures and are not subjected to any effort restrictions. Stock assessment in the Mediterranean has been seriously constrained by data limitations in the past. Occasionally, samplings over a short period were conducted for a small part of the target species, providing static pictures of the current situation and requiring restrictive equilibrium assumptions (Caddy 2009). The situation was considerably improved the last decade in the Mediterranean EU member states, after the implementation of the Data Collection Regulation (DCR) programme (EC 1543/2000; EC 1639/2001; EC 199/2008; EC 949/2008) that enabled a time series of effort and landings data in the Mediterranean to be build. In the present study, the Fcube approach was applied on demersal fisheries data of the Greek Aegean Sea (Eastern Mediterranean). The objectives of the present study were twofold: a) to explore the general applicability of the Fcube method in a no-TAC situation, and b) to identify the limitations of the method and 'tailor' it to data poor situations like the Mediterranean fisheries.

Material and Methods

Study area - Data

The selected study area was the Greek Aegean Sea (GFCM 37.3.1, GSAs 22 & 23). According to EU legislation, logbooks in the Mediterranean are not compulsory for vessels of <10 m total length (EC 2847/1993) or for landed net weight of fish <15 kg per species (EC 1967/2006). Moreover, because of the very large number of small vessels (11,500 < 10 m – 88%) and landing ports (> 600), complete recording of landings and effort from small-scale fisheries is impractical. Therefore, contrary to the data-rich demersal fisheries of the Atlantic EU waters (ICES areas), the eastern Mediterranean has a shortage of fisheries information, forcing the assessment to be based on a small sample of total landings and effort data. Under the Data Collection Regulation framework (EC 1543/2000; EC 1639/2001; EC 199/2008), data on effort and landings have been collected in Greece since 2002, from 30 major sites including 209 landing ports on a monthly basis, according to a systematic sampling procedure (Bazigos & Kavadas 2007). For the needs of this study, Greek data covering the period 2004–2006 were used.

Three stocks of demersal species were considered: hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), and striped red mullet (*Mullus surmuletus*). Their selection was based on three criteria: abundance, availability of biological parameters, and contribution to fishers' income. Socioeconomic data covered a series of parameters such as capital costs, fuel costs, crew cost, other variable costs, fixed costs, and market prices of sold fish. Effort was expressed in thousands of days at sea, catches (landings and discards) in tons, profits in thousands of Euros.

Fleet segmentation – métiers

Since one main concern of the managers is how to handle conflicts among fleets sharing the same stocks, only fleets with overlapping activities and interests were investigated. Such competition and conflicts exist only among trawlers and coastal boats. Purse-seiners and fleets targeting large pelagic species do not interact with the aforementioned fleets, either spatially or temporally, since they exploit different resources. Fleet segmentation was actually dictated by the way data are collected within the DCR sampling schemes, where boats are categorized by size and fishing technique used. Definitions of fleets and metiers used are consistent with the Data Collection Framework of European Commission (EC 199/2008). A fleet segment is defined as “a group of vessels with the same length class and predominant fishing gear during the year. A metier is “a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern”. So, in the same fleet segment, different metiers could be identified.

The active Greek trawler fleet in the Aegean Sea consists of 299 vessels that use bottom trawl net as the main gear (Table 1). The gear used is more or less the same (40 mm diamond mesh size) irrespective of the target species, with only minor modifications. Coastal vessels comprise > 92% of the Greek fleet (Table 1). The coastal fleet is engaged in a variety of different fisheries and each vessel shifts among several métiers during the year. These vessels mostly use static gears, i.e. gillnets, trammel nets, and static long lines, but some of them have a boat seine license as well and operate close to the coastline (< 0.5 mile) at depths < 50m.

Landings profiles were analyzed to identify potential métiers of both the bottom trawl and the coastal fleet, based on a large sample of landings from all over Greece. Fifty metiers were identified (6 belonging to the trawlers fleet and the rest to the coastal fleet) in the Aegean Sea (Katsanevakis *et al.* 2010 a; b; c). However, in the lack of métier-specific landings and effort data, such a level of disaggregation was not adequate for applying the Fcube approach, and thus a lower level of disaggregation was applied.

Four main fleet segments and four métiers were thus considered in this study. The fleet – métier combinations used in the analyses were:

- Trawl 12-24m - OTB: small sized bottom otter trawlers targeting demersal species.
- Trawl 24-40m - OTB: medium-large sized bottom otter trawlers targeting demersal species.
- Coastal 0-12m – NETS: small sized coastal fishery boats using gillnets or trammel nets (multi-specific fishery)
- Coastal 0-12m – LLS: small sized coastal fishery boats using static bottom longlines targeting mainly hake
- Coastal 0-12m – SV: small sized coastal boat seiners (multi-specific fishery)
- Coastal 12-24m – NETS: medium-large sized coastal fishery boats using gillnets or trammel nets
- Coastal 12-24m – LLS: medium-large sized coastal fishery boats using static bottom longlines targeting mainly hake

- Coastal 12-24m – SV: medium-large sized coastal boat seiners (multi-specific fishery)

Stock assessment

Although GFCM and STECF/SGMED (Scientific, Technical and Economic Committee for Fisheries, SubGroup on the Mediterranean) have produced a series of assessments on various Mediterranean demersal species, age-based analytical assessments have not been undertaken in the Aegean Sea. In the past, some exploratory approaches have investigated the stock status of Aegean hake in the framework of EU funded Projects (BECAUSE, EFIMAS, SAMED). As a result, for the needs of Fcube, detailed information regarding the stocks (total number of individuals, total biomass, survival rates, natural losses, fishing mortalities) were obtained applying stock assessment methods (VPA – Virtual Population Analysis; Pope 1972) on the catch data (pseudocohort). Vectors of fishing mortalities (*F*) by age were estimated and used as input to the Fcube implementation. Natural mortality was not assumed constant (as is the case in most studies) but we used a variable vector of values derived from the Chen-Watanabe equation (Chen & Watanabe 1989) for red mullet and striped red mullet and from Caddy & Abella (1999) for hake. Therefore M was variable across ages and not time. In Tables 2 and 3, the status of the three stocks (total population in No, total biomass, fishery related removals, fishing mortalities) and the corresponding biological parameters used for the VPAs, are presented respectively.

Fcube method

The Fcube method acknowledges that fleets can allocate their fishing effort across a range of different fisheries. Instead of only one incentive, like the single-species quota, fleets can respond to a range of different incentives – stock biomass, market conditions, regulations – and have a far wider range of responses at their disposal than simply to stop fishing. Taking as input some observed patterns of the fishery and fleets (landings, effort, catchability *q*, fishing mortality *F* by year, fleet, métier and stock), the Fcube method reproduces forecasts of the fleets reactions under different management actions. The core estimate of Fcube is effort, estimation of other parameters values for the forecast year (*q*, *F*) are based either on averages over recent years, or more complex approaches (behaviour algorithm-Andersen *et al*. 2010; consideration of economic optimisation-Hoff *et al*. 2010). The basic assumption is that a fleet may participate in more than one fishery, or metier, during a year, and that the fishing mortality exerted on a specific fish stock by the fleet is proportional to the effort used (Ulrich *et al.* 2008). This correspondence is used by Fcube to determine the effort needed by a fleet to catch each of its single-species quotas.

As mentioned above, the Greek fisheries are not regulated by TAC (except for bluefin tuna). In order to use the method, a set of virtual TACs and their corresponding fishing mortalities were applied. These were estimated using forward projections based on target fishing mortalities. Outlining the method: Fcube initially forecasts the effort by fleet corresponding to a single stock TAC and based on this effort, it forecasts the catch of each stock under various rules. Currently Fcube does not account for stock dynamics (e.g. recruitment) as well as spatiotemporal re-allocation of effort and catches. It is available within the FLEcon package, compatible with the open-source FLR simulation framework, which is used widely in the investigation of fishery-management problems (Fisheries Library in R, Kell *et al.*

2007; http://flr-project.org). Fcube inherently includes several sub-scenarios, which output results in every run:

a) "min" (stop fishing when first quota exhausted)
b) "max" (stop fishing when last quota exhausted)
c) "val" (effort directed towards most valuable quota shares - this scenario gives an effort weighted by the most valuable species, which may, however, not necessarily give the highest profit. This choice of effort is not based on economic optimization as has been applied in Hoff *et al.* 2010)
d) "SPECIES-*i*" (action necessary to avoid species-*i* over-quota catches for all fleets)
e) "statusquo_E" (unchanged effort between the historical years and forecast year)
f) "DAS_reduction" (Days At Sea partial reduction of effort on certain fleets). Here it was decided to investigate an arbitrary DAS_reduction of 8% on the effort of trawlers and 16% on the effort of the coastal fleet. These corresponded to a fishing ban of three and eight weeks respectively (Greek trawlers fishing period lasts 8 months (~35 weeks) whereas the coastal fleet fishes year round (52 weeks)).

The minimum, maximum and value scenarios do not reflect economic behaviour of the fishermen, i.e. acting as profit maximisers. Thus in addition to the above an extra scenario has been included, where effort is distributed freely among métiers while optimizing the total fleet profit, and at the same time complying with the single-species TACs. Thus the original Fcube model has been extended with an optimization module, the FcubEcon model (see for details Hoff *et al.*, 2010). The FcubEcon approach bases the management decision (distribution of effort and thus of single-species quotas) on economic optimisation considerations of the harvesting agents, meaning that FcubEcon, using the original Fcube framework, bases the effort-distribution between fleets and fisheries on optimisation of the profit (catch value minus costs) of the fleets involved. The optimisation is based on the projection the model does from 2004-2006 to 2007 and does not consider discount rates. In the present context this profit optimization has been applied both when calculating catches according to the traditional biological catch equation, and when calculating catches using Catch Per Unit Effort (CPUE) times effort. Unlike the Hoff et al. (2010) approach (which assumed a year round fishing period), herein certain effort constraints for the fleets have been considered, based on the current legislation and the respective seasonal closures. The detailed typology and mathematical formulations regarding the Fcube method as well as the economic optimization (FcubEcon) can be traced in the original works of Ulrich *et al*. (2008, 2011) and Hoff *et al.* (2010).

Fcube scenarios

Three different main scenarios were investigated using Fcube (E denotes effort, F fishing mortality, L landings). The historical stock catchabilities of the metiers were calculated by dividing their partial fishing mortality by their effort and the average catchability of years 2004 to 2006 was used for the forecast. This was based on an exploratory analysis, which identified no obvious trend in the annual catchabilities by metier.

The initial approach was to investigate the case in which the fleets retain their fishing effort constant in the forecast year (2007). This was called the NC scenario (Scenario 1: No Change) and had the following specifications: E_{NC}=E_{2006}, F_{NC} was the average fishing mortality between 2004–2006, and $TAC_{NC}=L_{NC}=L_{2006}$, which was 9077 t for hake (HAKE), 3076 t for red mullet (REDMUL), and 1926 t for stripped red mullet (STRMUL).

The other two scenarios 2 and 3 related to the reduction of fishing pressure on the hake stock, since it is most likely harvested beyond sustainable levels (Maravelias 2007; Papaconstantinou & Faruggio 2000). In the present study the effects of either a 10% reduction on hake fishing mortality (scenario 2: -10% F) or a 20% reduction of hake F (scenario 3: -20% F) were examined.

Results

Effort by fleet-métier, as well as corresponding landings for the last year of the study (2006) is shown in the bar-charts of Figs. 1 and 2. These figures show the important contribution of the small sized coastal-nets component of the fishery in the total effort exerted (“Coastal 0-12m – NETS”). Economic cost data for 2006 by fleet segment are given in Table 4.

Scenario 1

With the exception of “max” and “REDMUL” sub-scenarios that suggested a slight increase in the effort of all fleets (~2.8%), all other sub-scenarios imposed a significant decrease in fleets’ activities by as much as 33% in the “min” and “STRMUL” sub-scenarios (Table 5).

The estimated catches by Fcube (Fig. 3) were directly linked to the forecasted effort and the catchability by stock and metier.

From an economic perspective the “max” and “REDMUL” sub-scenarios were the most profitable for the fleets, suggesting that fishers income will not drop below their previous levels (Table 6), while “min” and “STRMUL” suggested cutbacks that, in the short term, reached 35% in the coastal boats and more than 20% in the trawlers.

The “DAS_reduction” scenario covers, to some extent, both biological (slight overquotas – few excess fish removals) and economic requirements (fishers income may reduce, in the short term, from 5% to 20% based on the fleet investigated). In the short term, substantial reduction of catches will be experienced mainly by the coastal fleet.

Economic optimization scenarios suggested that investigating economically optimal effort allocation between fleets, while complying with the TACs, may be rewarding. However the profits in the optimisation scenarios are not necessarily higher than the remaining scenarios since all of these assume some degree of overfishing.

Scenarios 2 and 3

Lowering hake fishing mortality for hake by 10% or 20% corresponded to a 5.7% or 11.8% decrease in landings, for scenarios 2 and 3 respectively. All sub-scenarios, except “max” and “REDMUL”, suggested a significant decrease in fishing effort (Tables 7 and 8), by as much as 35% and 42%, for 10% or 20% reduction on hake F respectively for the “min” and “HAKE” sub-scenarios. Catches for scenarios 2 and 3 are presented in Figs 4 and 5 respectively.

Economic outputs suggested that the “max” and “REDMUL” sub-scenarios were the most profitable for the fleets (Tables 9 and 10).

For scenario 2, the “STRMUL” sub-scenario was the least restrictive and gave only 1.1% hake overquota. This sub-scenario suggested that: (i) no excess catches for the remaining species will be observed, (ii) all fleets must reduce their activities by approximately 33%, (iii) all fleets will reduce their red mullets landings significantly, but coastal fleets will be the most affected and, (iv) short-term socio-economic impact will be considerable (income reduction: -20% in trawlers; -33% in coastal fleets) and a serious concern for the managers to confront.

For scenario 3, only the “min” or “HAKE” sub-scenarios met the biological requirements set and in this case: (i) no discards are to be expected, (ii) all fleets must lessen their activities by approximately 42%, (iii) red mullets landings will be reduced by more than 30% for all fleets with the small coastal boats being severely affected and, (iv) the short-term economic impact will be significant for the coastal boats (more than 40% income reduction) and considerable for the trawlers (approx. -30%).

The CPUE economic optimization scenario indicated that by re-allocating effort among fleets all segments (except larger trawlers) would substantially increase their profits (Tables 8 and 9). Evidently, limiting the activities of few large trawlers (174 boats) will be beneficial for the remaining larger part of the fleets (13288 boats).

Discussion

One of the most useful characteristics of the Fcube method is its ability to simulate and compare the outcomes of various management strategies under a mixed-fishery perspective. Other strengths of Fcube are its mathematical and conceptual simplicity, by attempting to model actual processes creating the situations of technical interactions, rather than implementing statistical estimates with weak theoretical basis. In the absence of reliable forecasts, Fcube can also be used as a tool for hind casting observed catches and effort patterns (ICES 2007). However, the method is largely dependent on catchability (q) and effort share. If the estimates of these parameters deviate far from the actual ones, great inconsistencies may arise in the effort and catch estimates, especially for fleets with very dissimilar exploitation patterns. In the present work, effort was measured in days at sea. The use of a more informative unit of effort (e.g. haul duration, swept area, length of net, number of hooks) could have probably resulted in improved estimates.

Notwithstanding these limitations, the application of Fcube in the Aegean Sea's data of four major fleets sharing three major stocks was valuable for a number of reasons. Not only was it beneficial in estimating catch under various management scenarios, but more importantly through the allocation of effort between different fleets and métiers it revealed the importance of effort and catches control in a group of fisheries that are largely managed through rather simple technical measures such as minimum landing sizes and mesh sizes (i.e. coastal fisheries using nets and longlines).

The allocation of effort between fisheries is most effectively achieved by the "Days At Sea reduction" sub-scenario. However, it is difficult to say how other species, not considered in this study, would be affected and how effort may be re-allocated spatially. Seasonal closures are already in action and "inbuilt" in the culture of Greek modern trawl fisheries, making "DAS reduction" a more plausible management strategy than setting actual TAC's.

Selection of the most appropriate management strategy becomes a more difficult task when stricter F reduction objectives are set (scenarios 2 and 3). To meet the desired objectives, sub-scenarios with significant effort reductions had to be chosen, such as the "STRMUL" sub-scenario to achieve 10% reduction on hake fishing mortality or the "min" sub-scenario to achieve 20% reduction on hake fishing mortality. Especially the introduction of the "min" option for scenario 3 may require socio-economic measures for compensation (e.g. subsidies). Here, the "DAS_reduction" scenario, which could appear more 'attractive' to Mediterranean fisheries managers seems ineffective, since it cannot meet either hake or striped red mullet's biological objectives.

In most of the scenarios investigated, single-species management objectives failed to be reached simultaneously in the short-term. One way to remedy this concern may be to depend more on effort-based control of vessel activities than on single-stock management objectives and TAC's. The Fcube methodology, adapting total effort and re-allocating it among the various fleets, may prove useful to this end.

When scientific advice advocates that the stocks are under alarming fishing pressure, then priority should be given to rebuilding target exploitation levels consistent with high long term yields. To achieve that, stricter management measures may be required. In this case the “min” scenario, allowing for overquota catches including discards would be recommended. The socio-economic aspect of all the scenarios investigated suggested that, if the objectives have to be met, then considerable reductions in fishers’ income will take place in the short-term. Multi-annual fisheries management plans with predefined management goals consistent with sustainable high long term yields should be developed to avoid such negative short term effects and to improve the socio-economic situation of the mixed demersal fisheries sector in the Aegean Sea. The fundamental challenge of fisheries management is to balance the economic needs across a wide range of fishery participants with the biological “needs” in terms of conservation. The Fcube scenarios explored can be utilized as a tool for policy analysis to better understand pathways of development and to assess the impact of alternative policies on the natural resource base and human welfare. One of the potential benefits of the current models is that one can get a better and more comprehensive indication of the feedback effects between human activity and fishery resources. Evidently the collection of economic information regarding the fisheries and fleets involved is a prerequisite for the above.This study is the very first approach to apply a multi-species bio-economic evaluation of these fisheries in the eastern Mediterranean Sea. Future improvements in the application of the Fcube method in the area could be: a) the assessment of more commercial demersal species, b) the analysis of longer time series of data, c) the further disaggregation of fleet activities to more métiers, d) the accurate quantification of fishing mortality and catchability. Fishing mortality estimation remains imprecise because, in addition to the reported catch, there are other unaccounted sources of fishing mortality e.g. illegal, unreported and unregulated fishing (IUU), ghost fishing. The lack of such information may lead to erroneous conclusions and recommendations in assessment, which have a bearing on the input data for Fcube (Ulrich *et al*. 2011).

A key achievement of the present study was the demonstration that while Fcube was initially developed to address single-stocks TACs issues in the northern European waters, it also proved applicable in fisheries management systems without TACs. Through the allocation of effort among different fleets and métiers, Fcube revealed the importance of effort control in a group of fisheries (i.e. Aegean sea coastal fisheries) that are still managed without effort restrictions. The current work demonstrated how single-stocks objectives can be translated into effort levels instead of catch levels under certain assumptions, and thus how management strategies could be advanced based on these in no-TAC regulated fisheries. As such, this study contributed significantly to the general development of the Fcube methodology, ensuring its wider generality and use.

References

Andersen B.S., Vermard Y., Ulrich C., Hutton T. & Poos J.J. (2010) Challenges in integrating short-term behaviour in a mixed-fishery management strategy evaluation framework: a case study of the North Sea flatfish fishery. *Fisheries Research* **102**, 26-40.

Bazigos G. & Kavadas S. (2007) Optimal sampling designs for large-scale fishery sample surveys in Greece *Mediterranean Marine Science* **8**, 65-82.

Caddy J.F. (1998) Issues in Mediterranean fisheries management: geographical units and effort control. Studies and Reviews. *General Fisheries Council for the Mediterranean*. No. 70. Rome, FAO. 56 pp.

Caddy J.F. (2009). Practical issues in choosing a framework for resource assessment and management of Mediterranean and Black Sea fisheries. *Mediterranean Marine Science* **10**, 83–119.

Caddy J.F. & Abella A.J. (1999) Reconstructing reciprocal M vectors from length cohort analysis (LCA) of commercial size frequencies of hake, and fine mesh trawl surveys over the same grounds. *Fisheries Research* **41,** 169-175.

Chen S.B. & Watanabe S. (1989) Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakkaishi* 55:205-208.

Da-Rocha Álvarez J.M. & Gutiérrez Huerta M.J. (2005) A Dynamic Stochastic Approach to Fisheries Management Assessment: An Application to some European Fisheries. Fundación BBVA, Editor. Plaza de San Nicolás, 4. 48005 Bilbao, 70pp.

de Pontual H., Bertignac M., Battaglia A., Bavouzet G., Moguedet, P. & Groison A.L. (2003) A pilot tagging experiment on European hake (Merluccius merluccius):

methodology and preliminary results. *ICES Journal of Marine Science* **60**, 1318–1327.

EC (1993) European Council Regulation establishing a control system applicable to the common fisheries policy. Regulation 2847/1993, OJ L 261/1. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31993R2847:EN:HTML

EC (2000) Council Regulation (EC) No 1543/2000 of 29 June 2000 establishing a Community framework for the collection and management of the data needed to conduct the common fisheries policy. OJ L 176, 15.7.2000, p. 1–16. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000R1543:EN:HTML

EC (2001) Commission Regulation (EC) No 1639/2001 of 25 July 2001 establishing the minimum and extended Community programmes for the collection of data in the fisheries sector and laying down detailed rules for the application of Council Regulation (EC) No 1543/2000. OJ L 222, 17.8.2001, p. 53–115. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32001R1639:EN:HTML

EC (2002) Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. OJ L 358, 31.12.2002, p. 59–80. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002R2371:EN:HTML

EC (2006) European Council Regulation concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94.

Regulation 1967/2006, OJ L 409/11. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:409:0011:0085:EN:PDF

EC (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance) OJ L 164, 25.6.2008, p. 19–40. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:01:EN:HTML

EC (2008) Council Regulation (EC) No 199/2008 of 25 February 2008 concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. OJ L 60, 5.3.2008, p. 1–12. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:060:0001:01:EN:HTML

EC (2008) Commission Decision of 6 November 2008 adopting a multiannual Community programme pursuant to Council Regulation (EC) No 199/2008, establishing a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy. OJ L 346, 23.12.2008, p. 37–88. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:346:0037:01:EN:HTML

EC (2006) European Council Regulation concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending

Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94. Regulation 1967/2006, OJ L 409/11.

EC (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance) OJ L 164, 25.6.2008, p. 19–40.

FAO (2010) Regional Fishery Bodies (RFB) - Web Site. Regional Fishery Bodies (RFB). FI Institutional Websites. *In*: FAO Fisheries and Aquaculture Department [online]. Rome. http://www.fao.org/fishery/rfb/en

GFCM (2010) Management of Mediterranean Fisheries. General Fisheries Commission for The Mediterranean. 34th Session Athens, Greece, 14-17 April 2010. GFCM Document XXXIV/2010/4. Available at: http://151.1.154.86/GfcmWebSite/GFCM/34/GFCM34_2010_4-e.pdf

Hoff A., Frost H. & Ulrich C. (2009) An economic approach to overcoming over-quota catches in multi-species fisheries: The FcubEcon model. ICES CM / O:05.

Hoff A., Frost H., Ulrich C., Damalas D., Maravelias C.D., Goti L. & Santurtún M. (2010) Economic effort management in multispecies fisheries: the FcubEcon model. *ICES Journal of Marine Science* **67**, 1802-1810.

ICES (2006) Report of the Workshop on Simple Mixed Fisheries Management Models (WKMIXMAN), 9–13 January 2006, ICES Headquarters. ICES CM 2006/ACFM:14. 47 pp. Available at: http://www.ices.dk/reports/ACFM/2006/WKMIXMAN/WKMIXMAN06.pdf

ICES (2007) Report of the Study Group on Mixed Fisheries Management (SGMixMan), 15-19 January, ICES HQ, Copenhagen, Denmark. ICES CM 2007/ACFM:02. 565 pp. Available at:

http://wiki.difres.dk/efimas/lib/exe/fetch.php?media=efimas1:wp4:cs2:appr1:sgmixman08.pdf

ICES (2008) Report of the Study Group on Mixed Fisheries Management (SGMixMan), 14-18 January, ICES HQ, Copenhagen, Denmark. ICES CM 2007/ACOM:23. 65 pp.

ICES (2009) Report of the Workshop on Mixed Fisheries Advice for the North Sea (WKMIXFISH), 26-28 August, ICES HQ, Copenhagen, Denmark. ICES CM 2009/ACOM:47. Available at: http://www.ices.dk/reports/ACOM/2009/WKMIXFISH/WKMIXFISH%202009.pdf

Katsanevakis S., Maravelias C.D. & Vassilopoulou C. (2010a) Otter trawls in Greece: Landing profiles and potential métiers. *Mediterranean Marine Science* **11**, 43-59.

Katsanevakis S., Maravelias C.D. & Kell L.T. (2010b) Landings profiles and potential métiers in Greek set longliners. *ICES Journal of Marine Science* **67**, 646-656.

Katsanevakis S., Maravelias C.D., Vassilopoulou V. & Haralabous J. (2010c) Boat seines in Greece: Landings profiles and identification of potential métiers. *Scientia Marina* **74**, 65–76.

Kell L.T., Mosqueira I., Grosjean P., Fromentin J-M., Garcia D., Hillary R., Jardim E., Mardle S., Pastoors M.A., Poos J.J., Scott F. & Scott R.D. (2007) FLR: an open-source framework for the evaluation and development of management strategies. *ICES Journal of Marine Science* **64,** 640–646.

Machias A., Somarakis S. & Tsimenides N. (1998) Bathymetric distribution and movements of red mullet *Mullus surmuletus*. *Marine Ecology Progress Series* **166**, 247-257.

Maravelias C.D. (2007) Bayesian Risk Assessment in Hellenic Fisheries Management. State of Hellenic Fisheries. *In* SoHelFI State of Hellenic Fisheries. *Edited by* C. Papaconstantinou, A. Zenetos, V. Vassilopoulou & G. Tserpes. HCMR Publ. pp. 320-326.

Papaconstantinou C. & Faruggio H. (2000) Fisheries in the Mediterranean. *Meditteranean Marine Science* **1,** 5-18.

Pope J.G. (1972) An investigation of the accuracy of virtual population analysis using cohort analysis. *International Commission for the Northwest Atlantic Fisheries Research Bulletin* **9**, 65-74.

Reeves S. & Ulrich C. (2007) Bridging the gap: fleets, fisheries and the ecosystem approach. ICES CM 2007/R: 02.

Tserpes G. (1996) Contribution to the study of the dynamics and fisheries exploitation of the demersal fisheries resources of Cretan waters. PhD Thesis, Heraklion: University of Crete, 189 pp.

Ulrich C., Reeves S.A. & Kraak S.B.M. (2008) Mixed Fisheries and the Ecosystem Approach. ICES INSIGHT Issue No. 45, p.36-40.

Ulrich C., Reeves S.A., Vermard Y., Holmes S. & Vanhee W. (2011) Reconciling single-species TACs in the North Sea demersal fisheries using the Fcube mixed-fisheries advice framework. *ICES Journal of Marine Science*, In press.

UN (2002) Report of the World Summit on Sustainable Development (United Nations publication, A/CONF.199/20), Johannesburg, South Africa, 26 August-4 September 2002, 173 pp. Available online at: http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement.

Vinther M., Reeves S. & Patterson K. (2004) From single-species advice to mixed-species management: taking the next step. *ICES Journal of Marine Science* **61**, 1398-1409.

TABLES

Table 1: Fishing vessel characteristics by fleet segment in the Aegean Sea, in 2006.

Fleet	Number of boats	Average Length (m)	Average engine power (KW)
Coastal 0-12m	12746	6.7	20.1
Coastal 12-24m	417	13.8	93.1
Trawl 12-24m	125	21.3	277.7
Trawl 24-40m	174	28.1	317.7

Table 2. Basic stock parameters values used as inputs in Fcube.

	M. merluccius			*M. barbatus*			*M. surmuletus*		
	2004	2005	2006	2004	2005	2006	2004	2005	2006
Total population N	141,770,128	198,645,205	216,733,088	418,649,399	438,988,985	344,625,848	278,477,788	208,823,193	187,348,335
Total Biomass tons	20,067	29,455	27,272	9492	9902	8737	9720	6888	6881
Total Landings tons	7615	8513	9077	3438	3556	3096	2675	1986	1951
Total Catches tons	9487	13725	13245	3453	3620	3159	2795	2089	1970
Fishing mortality F	1.011	1.038	1.119	0.397	0.380	0.347	0.358	0.341	0.272

Table 3. Basic biological parameters values for the stocks investigated in Fcube

Stock	Parameter						Source
	$L\infty$ (mm)	k	t_0	a(W-L)	b(W-L)	M	
M. merluccius	1100	0.25	-0.35	0.00000398	3.11	0.93	de Pontual *et al.*, 2003
M. barbatus	318	0.13	-2.55	0.00000316	3.25	0.39	Tserpes G., 1996
M. surmuletus	354	0.23	-1.194	0.00000955	3.04	0.76	Machias *et al*., 1998

Table 4. Basic economic parameters for the Aegean Sea fleet segments in 2006.

Fleet	Coastal 0-12m	Coastal 12-24m	Trawl 12-24m	Trawl 24-40m
Income (x1000 €)	192,526	7,746	36,042	118,005
Costs (x1000 €)	98,553	3,017	29,423	74,882
Fleet (No of boats)	12,746	417	125	174

Table 5. Scenario 1; percentage change in effort for the various sub-scenarios in relation to the 2006 exerted effort.

Sub-scenario	% change in effort in relation to 2006			
	Coastal 0-12m	Coastal 12-24m	Trawl 12-24m	Trawl 24-40m
Max	2.7	2.8	2.9	2.8
Min	-33.8	-33.7	-33.7	-33.7
Val	-23.2	-27.2	-18.5	-22.6
HAKE	-28.3	-28.2	-28.2	-28.2
REDMUL	2.7	2.8	2.9	2.8
STRMUL	-33.8	-33.7	-33.7	-33.7
statusquo_E	0.0	0.1	0.2	0.1
DAS_reduction	-15.8	-14.2	-7.9	-7.9

Table 6. Scenario 1; economic outputs of the 8 sub-scenarios and the economic optimizations scenarios investigated (values are in 1000€)

Profit per Vessel (1000 €)	sub-scenario							
Fleet	max	min	val	HAKE	REDMUL	STRMUL	statusquo_E	DAS_reduction
Coastal 0-12m	37.9	25.3	29.1	27.3	37.9	25.3	37.0	30.5
Coastal 12-24m	211.9	140.9	153.0	151.8	211.9	140.9	206.7	176.1
Trawl 12-24m	97.6	78.4	91.9	82.4	97.6	78.4	96.7	93.4
Trawl 24-40m	424.5	312.9	350.5	331.7	424.5	312.9	417.2	395.6

Table 7. Scenario 2; percentage change in effort for the various sub-scenarios in relation to the 2006 exerted effort

Sub-scenario	% change in effort in relation to 2006			
	Coastal 0-12m	Coastal 12-24m	Trawl 12-24m	Trawl 24-40m
Max	2.7	2.8	2.9	2.8
Min	-35.5	-35.4	-35.4	-35.4
Val	-26.7	-32.5	-22.7	-27.7
HAKE	-35.5	-35.4	-35.4	-35.4
REDMUL	2.7	2.8	2.9	2.8
STRMUL	-33.8	-33.7	-33.7	-33.7
statusquo_E	0.0	0.1	0.2	0.1
DAS_reduction	-15.8	-14.2	-7.9	-7.9

Table 8. Scenario 3; percentage change in effort for the various sub-scenarios in relation to the 2006 exerted effort

Sub-scenario	% change in effort in relation to 2006			
	Coastal 0-12m	Coastal 12-24m	Trawl 12-24m	Trawl 24-40m
Max	2.7	2.8	2.9	2.8
Min	-42.4	-42.4	-42.3	-42.4
Val	-30.1	-37.6	-26.8	-32.7
HAKE	-42.4	-42.4	-42.3	-42.4
REDMUL	2.7	2.8	2.9	2.8
STRMUL	-33.8	-33.7	-33.7	-33.7
statusquo_E	0.0	0.1	0.2	0.1
DAS_reduction	-15.8	-14.2	-7.9	-7.9

Table 9. Scenario 2; economic outputs of the 8 sub-scenarios and the economic optimizations scenarios investigated (values are in 1000€)

Profit per Vessel (1000 €)	sub-scenario							
Fleet	max	min	val	HAKE	REDMUL	STRMUL	statusquo_E	DAS_reduction
Coastal 0-12m	37.9	24.7	27.9	24.7	37.9	25.3	37.0	30.5
Coastal 12-24m	211.9	137.5	142.4	137.5	211.9	140.9	206.7	176.1
Trawl 12-24m	97.6	77.1	89.3	77.1	97.6	78.4	96.7	93.4
Trawl 24-40m	424.5	306.8	332.0	306.8	424.5	312.9	417.2	395.6

Table 10. Scenario 3; economic outputs of the 8 sub-scenarios and the economic optimizations scenarios investigated (values are in 1000€)

Profit per Vessel (1000 €)	sub-scenario							
Fleet	max	min	val	HAKE	REDMUL	STRMUL	statusquo_E	DAS_reduction
Coastal 0-12m	37.9	22.2	26.7	22.2	37.9	25.3	37.0	30.5
Coastal 12-24m	211.9	123.4	132.0	123.4	211.9	140.9	206.7	176.1
Trawl 12-24m	97.6	71.1	86.7	71.1	97.6	78.4	96.7	93.4
Trawl 24-40m	424.5	281.0	313.3	281.0	424.5	312.9	417.2	395.6

FIGURE LEGENDS

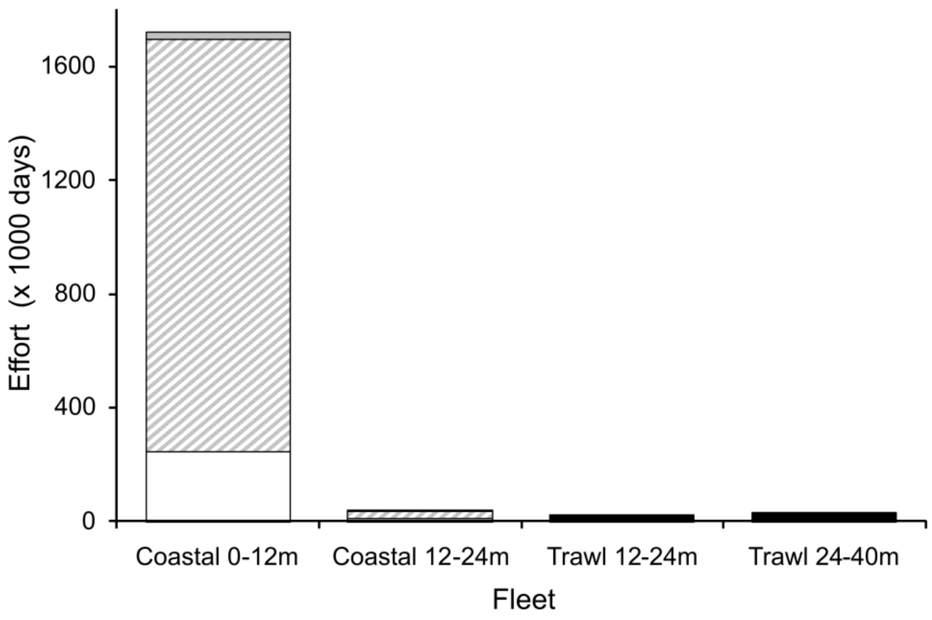
Fig. 1. Effort exerted by fleet and métier during 2006. (OTB: black fill, LLS: white fill, NETS: striped fill, SV: grey fill)

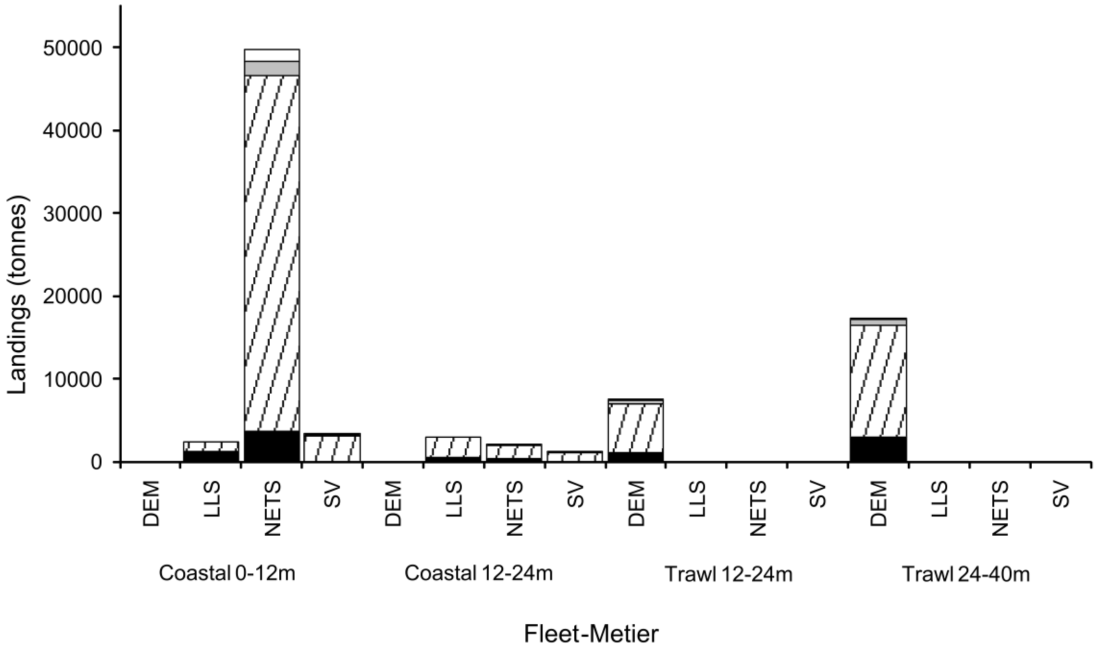
Fig. 2. Landings by fleet and métier during 2006. (HAKE: black fill, OTHERS: striped fill, REDMUL: grey fill, STREDMUL: white fill)

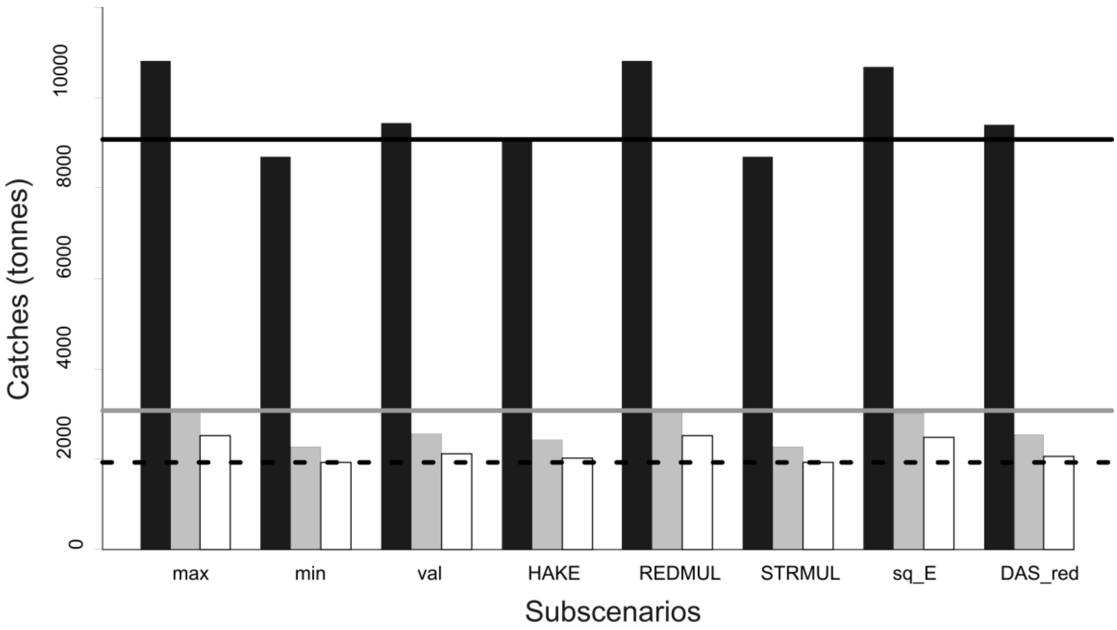
Fig. 3. Scenario 1 Fcube output (catches in tons in the forecast year 2007) of the possible sub-scenarios of effort management proposed (horizontal lines indicate corresponding stock TAC’s). (HAKE: black fill, REDMUL: grey fill, STREDMUL: dotted fill)

Fig. 4. Scenario 2 Fcube output (catches in tons in the forecast year 2007) of the possible sub-scenarios of effort management proposed (horizontal lines indicate corresponding stock TAC’s). (HAKE: black fill, REDMUL: grey fill, STREDMUL: dotted fill)

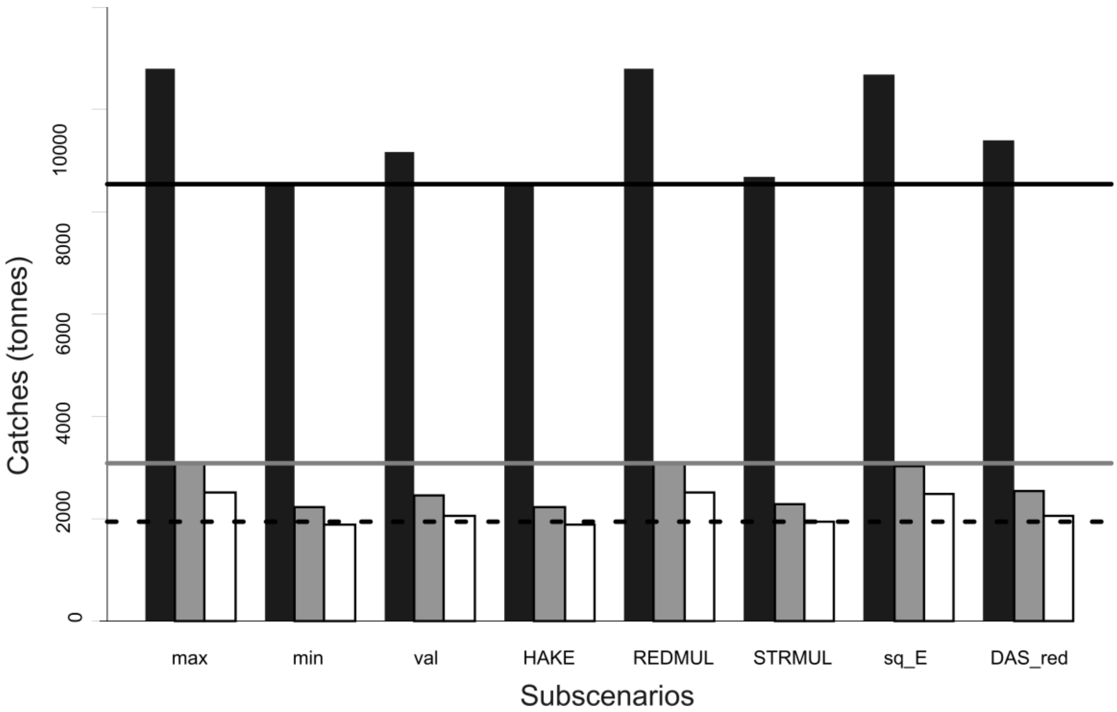
Fig. 5. Scenario 3 Fcube output (catches in tons in the forecast year 2007) of the possible sub-scenarios of effort management proposed (horizontal lines indicate corresponding stock TAC’s). (HAKE: black fill, REDMUL: grey fill, STREDMUL: dotted fill)

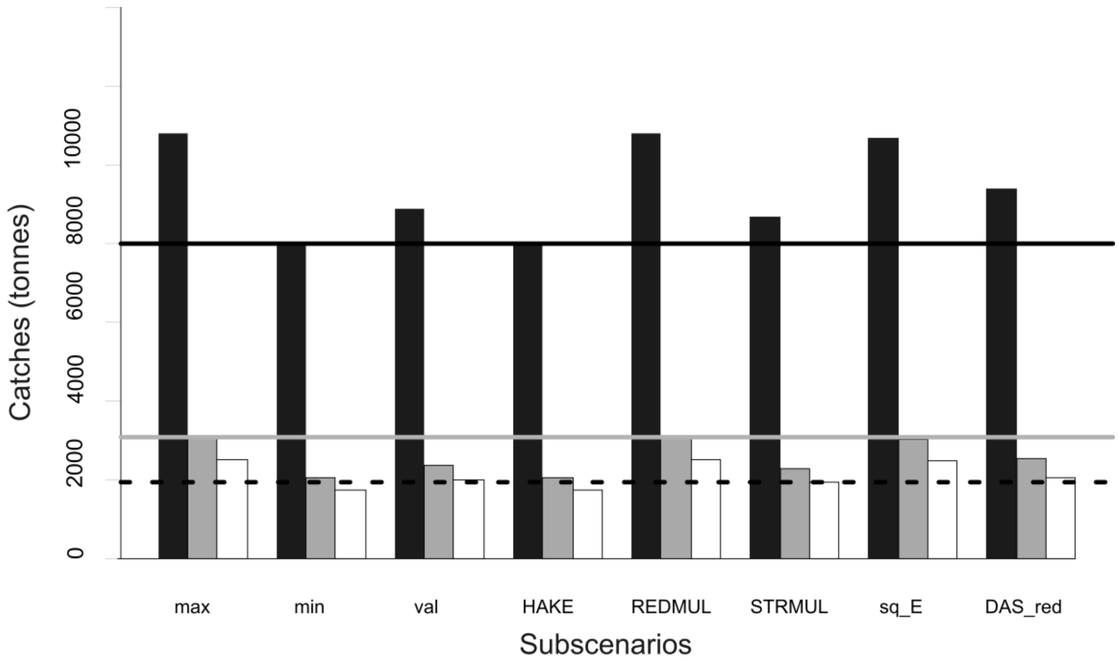

Effort (x 1000 days)
1600
1200
800
400
0
Coastal 0-12m
Coastal 12-24m
Trawl 12-24m
Trawl 24-40m
Fleet


50000
40000
30000
20000
10000
0
Landings (tonnes)
DEM
LLS
NETS
SV
DEM
LLS
NETS
SV
DEM
LLS
NETS
SV
DEM
LLS
NETS
SV
Coastal 0-12m
Coastal 12-24m
Trawl 12-24m
Trawl 24-40m
Fleet-Metier



Catches (tonnes)
0
2000
4000
6000
8000
10000
max
min
val
HAKE
REDMUL
STRMUL
sq_E
DAS_red
Subscenarios


Catches (tonnes)
0
2000
4000
6000
8000
10000
max
min
val
HAKE
REDMUL
STRMUL
sq_E
DAS_red
Subscenarios



Catches (tonnes)
0
2000
4000
6000
8000
10000
max
min
val
HAKE
REDMUL
STRMUL
sq_E
DAS_red
Subscenarios